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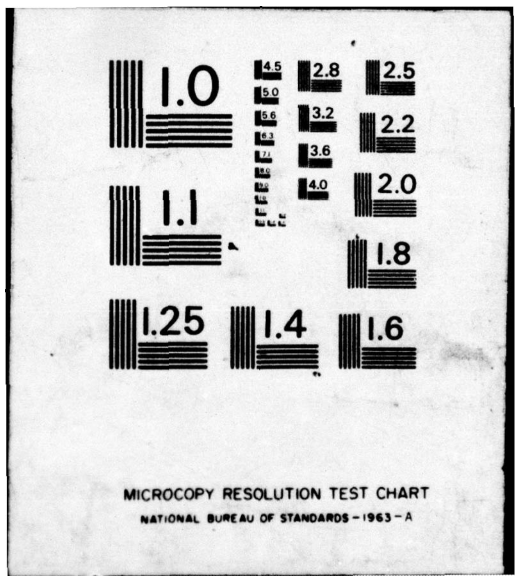
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FINAL SCIENTIFIC REPORT

SELECTED PROBLEMS IN SYSTEM ENGINEERING

AFOSR 73-2427

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Submitted by

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and

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SELECTED PROBLEMS IN SYSTEMS ENGINEERING

Introduction

Research conducted under Grant AFOSR 73-2427 is related to various aspects of the continuing evolution of system theory. In highlighting this research it is convenient to focus attention on three continuing themes. The complimentary nature of these three research themes provides a cross reinforcement which is resulting in a well rounded theory.

The first continuing theme deals with the various shades of causality (anticausality) that system models can have and the interrelationship between these causality properities and such other system properties as stability, sensitivity and optimality. The vehicle for this research is the resolution space, a concept which embraces both linear and non-linear problems with equal facility.

The second theme concerns the class of systems describable by polynomic operators. The polynomic operators include the linear case and as such provide a natural bridge between the linear and nonlinear theory. More importantly polynomic behavior is the primary model for a large and diverse range of physical, biological, physiological and engineering and system science phenomena.

The third theme concerns the modeling of arbitrary systems by systems of a particular type. In part such studies provide a rigorous mathematical justification for typical modeling assumptions. More importantly this line of research has developed preliminary synthesis tools even when the design specification is in very unstructured form.

The complimentary nature of the above three themes is readily seen in the studies conducted under this grant. For example, the implications of the causality structure of polynomic operator are quite far reaching. In the same sense the

approximation of continuous causal functions by causal polynomic functions combines all three themes. The interrelationship is also evident in the publications touched on later in this report.

In addition to the technical features of the research there are two other features worth noting here. First the concept of 'state' is irrelevant to most of the research, and this is felt to be a distinctive feature. Secondly, portions of the research are related to the Russian school centered on the work of M.S. Brodskii, I.C. Gohberg, M.G. Krein, M.S. Livsic and others. Spot monitoring of their progress was carried out during the course of the grant.

Results and Problems

The concept of causality (respectively anticausality) is an intuitive feature of any system theory. It has become recognized, however, that refinement of the causality concept is necessary to capture the essence of such diverse devices as pure gain amplifiers, delay lines, differential equations, random processes, and non real time data processing systems. While several authors have proposed causality structures the most careful and comprehensive study is that of DeSantis and the principal investigator [1]. The causality classes identified in that study have proved to be a sufficient foundation for the research conducted under this grant.

During the grant emphasis was placed on utilizing the existing causality structure. References [3], [4], [10], for example are indicative of attempts to relate closed loop system stability to the strict causality of the open loop plant. The references [5], [7], [18], [19], are indicative of the use of causality structures in system sensitivity analysis. An overview of the system sensitivity area is available in [2].

Concerning the polynomic operators a comprehensive survey of the relevant literature is given in [16]. We mention here that it is known (see [11]) that every causal continuous function (on a Hilbert Resolution Space) has an approximation by a finite causal polynomic function. This establishes the polynomic systems as a large and important class. In reference [9], [20], [3], [14], it is shown that polynomic models are natural in system identification. References [10] and [18] analyze stability and sensitivity problems related to polynomic systems with feedback. Reference [3] views parametric excitation as a form of polynomic behavior and applies prior results to this special class of systems.

The polynomic approximation problem cited above deserves further mention. The flavor of the results of [11] is indicated by the following.

Let f be a continuous causal system on a Hilbert resolution space. Let K be any compact set of inputs and $\epsilon > 0$. Then there exists a causal polynomic system such that

$$\sup_{x \in K} \| f(x) - \hat{f}(x) \| < \epsilon .$$

The result of [11] is not constructive in that it does not tell how to find $\hat{f}$.

Toward the end of the grant a constructive realization of the Weierstrass result was achieved. In this the Bernstein polynomials were generalized to a Hilbert resolution space setting with a resultant structure realization. This approach was suggested by the fact that the Bernstein polynomials on the interval $0 \leq x \leq 1$ do realize the Weierstrass result of this compact set.

During the latter stages of the grant attention has been given to the following problem. Given a set $\{(u_i, y_i)\}_1^n$, of input-output pairs, characterize all causal operators, T, which satisfy $y_i = Tu_i$, i+1,....,n. It was determined (Reference [9]) when a solution exists and when this solution can be linear. Furthermore,

explicit solution techniques are in hand. All possible solutions to the problem have also been characterized.

During the last grant year work in this area was focused on other additional constraints. For instance, letting the resolution space be $L_2(\tau)$, one can synthesize the causal operator solution as a differential equation (see [20]). Potential applications are manyfold. First, there is a strong connection with pattern identification problems, [23] i.e., $\{u_i\}$ are the patterns, $\{y_i\}$ the signatures and T is the pattern recognizer. Secondly, there is a connection and fault detection where in $\{u_i\}$ are possible fault categories and $\{y_i\}$ are the desired fault signatures.

During the grant the principal investigator's curiosity led to consideration of resolution spaces over a finite modulo field. This in turn resulted in a short study, (which is not being continued) of the modeling of finite state devices. The results of this study are reported in [17], [21] and [22]. An application of resolution space modeling techniques is also being pursued under an NSF grant, with [15] being one of the early publications.

Other Activities

During the grant period the principal investigator was involved in several activities of related interest. Research under the grant is often complimentary to the work of Professors Richard Saeks and Romano DeSantis. During the grant period an exchange of visits was arranged at the institutions of these two individuals and a thorough review of mutual interests and prospects for unresolved problems has resulted. The principal investigator also served as an IEEE Proceedings guest editor for the January 1976 special issue 'Recent Trends in System Theory', and also is serving on the administrative committee of the International Symposium on Operator Theory of Networks and Systems. In the same vein, the papers [6], [8]

[12], [13] were solicited on the grant research by the organizers of the conferences in question.

Closure

Because of the inherent delay between results and publication our summary has touched on several 1977 articles. These will, of course, be distributed as availability permits according to the conventional AFOSR procedures.

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This final scientific report describes the research carried out in three areas of system science: (a) the several notions of causality and their connections with stability, sensitivity, and optimality; (b) various questions regarding polynomic operators, a useful class of operators that contains the linear operators; and (c) the modeling of arbitrary systems by simpler systems of a specified type.